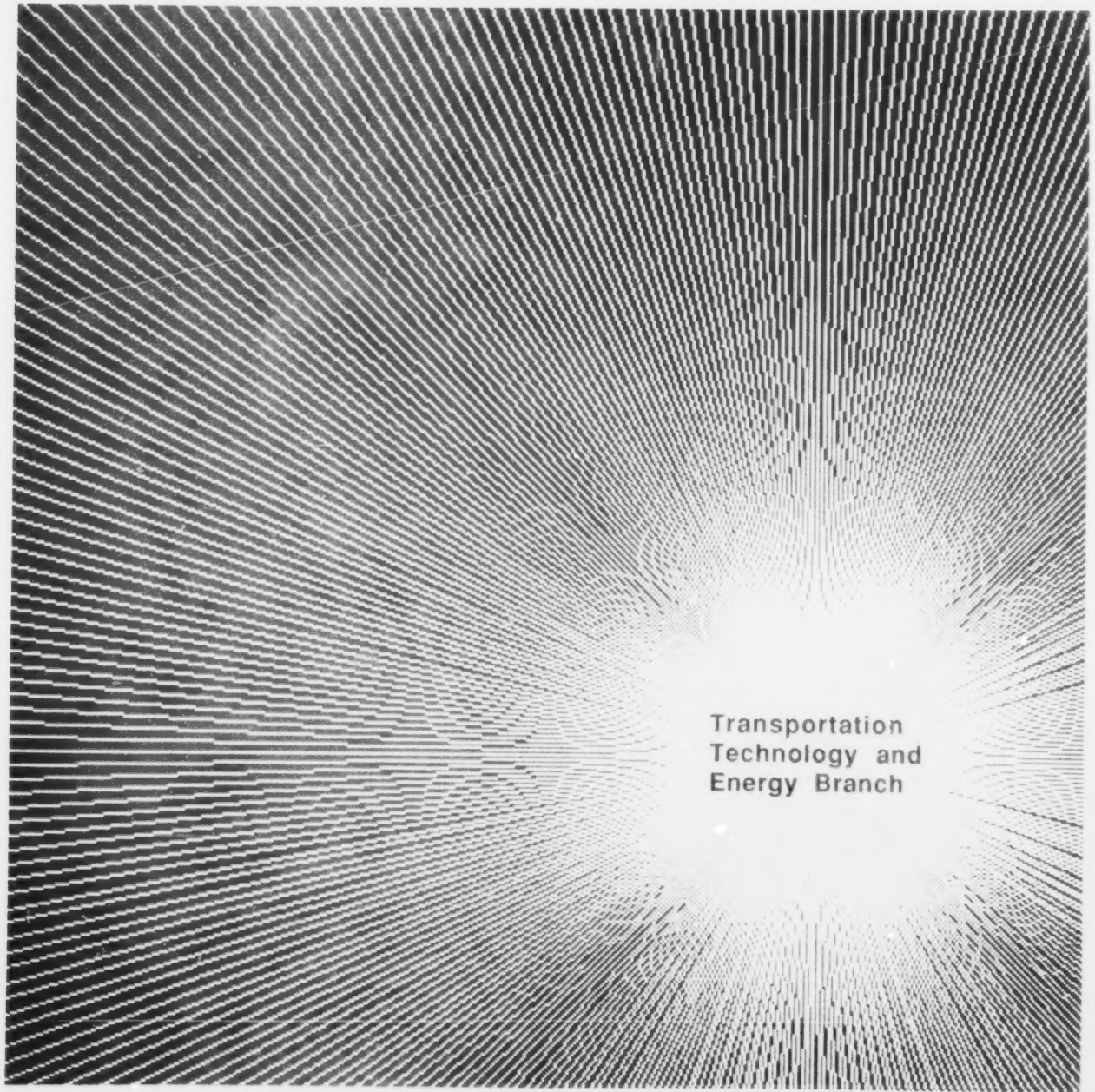




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**A Comparison of the
Durability of Methanol and
Gasoline Fuelled Vehicles**

AF-88-05

A Comparison of the Durability of Methanol- and Gasoline-Fuelled Vehicles

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Abstract: A fleet of Ford Escorts has been evaluated for engine durability. Five of the vehicles operated on near-neat methanol fuel ("fuel-methanol") while two operated on gasoline. Durability was determined by both pre- and post-measurement of engine components and analysis of the vehicle's used engine oil at regular intervals. Fuel consumption and maintenance problems were also monitored. Results indicate that engine wear was not significantly worse with the fuel-methanol cars. Deposits were lower with the fuel-methanol cars. However the three high mileage fuel-methanol cars suffered premature engine failures due to preignition initiated damage.

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Ford of Canada Limited
Ontario Ministry of Energy
Energy, Mines and Resources Canada
Ontario Ministry of Transportation

Key words: methanol-fuelled vehicles, engine durability, lubricants, cold weather performance

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EXECUTIVE SUMMARY

This report contains the conclusion of a long-term study of the engine durability of a group of methanol fuelled Ford Escorts, carried out by Ford of Canada and Shell Canada. The program was jointly supported by the participants and by the provincial and federal governments under the Transportation Energy Management Program (TEMP), and administered by the Ontario Ministry of Transportation and the Ontario Ministry of Energy. These vehicles were part of a fleet specially developed by the manufacturer to run on a mixture of 85% methanol and 15% gasoline (M85) and supplied for evaluation. Alterations to the standard Escort included increased compression ratio of 11.8:1, increased carburetor fuel delivery, nickel-plated components throughout the fuel system with stainless steel fuel tank and supply line, higher power electrically heated early fuel evaporator, and a revised spark plug timing curve.

Five methanol-fuelled vehicles were compared with two gasoline-fuelled Escorts. At the beginning of this test, two methanol and two gasoline vehicle engines were stripped and the dimensions of important wear-prone components recorded. A special oil formulation was devised for the test, derived from experience in earlier phases of the program. Progress was monitored by periodically analyzing used engine oil for quality changes and wear metal accumulation. The four pre-measured engines were stripped at the end of the test to check actual component wear.

During the test period, some higher levels of wear metals were observed for the methanol-fuelled vehicles, e.g., aluminum (two times), chromium (two to four times), and copper (up to two times). Other elements were about the same as for gasoline. Aluminum is considered to arise from increased corrosion of the many aluminum parts in the intake system, due to methanol, e.g., intake manifold and cylinder head, while chromium indicates piston ring wear. Quality changes in the oil were comparable for the two fuels, but the methanol engines had less than half the drain interval time compared with the gasoline engines, so that oil deterioration per kilometre was somewhat worse. Nevertheless, oil quality at drain interval was considered to be within acceptable limits for both fuels.

Near the end of the designated distance accumulation period, both methanol vehicles showed signs of deteriorating performance attributed to pre-ignition, a known problem with methanol engines. The engines were stripped and cracks in the cylinder head were found along with some dished valves – signs of overheating due to pre-ignition. Elsewhere, comparison with the gasoline engines showed increased ring wear but less wear in bearing shells and camshaft lobes. The latter may be partly due to the lower drain interval with methanol. The methanol engines showed lower sludge and engine deposits but greater carburetor deposits.

The main conclusion is that this particular engine is vulnerable to pre-ignition damage, probably because it was not designed for the increased compression ratio. Design improvements would be needed to gain acceptable durability, particularly for the Canadian climate where engine wear is likely to be most severe.

NOMENCLATURE

cst	- centistokes
CR	- Co-ordinating Research Council
Δ km	- difference in kilometres
EP	- end point
EPA	- Environmental Protection Agency
E	- exhaust
IBP	- initial boiling point
I	- intake
KOH	- potassium hydroxide
MJ	- megajoules
MeOH	- methanol
OHC	- overhead cam
ppm	- parts per million
% evap	- % evaporated in the ASTM-D-86 distillation test
RVP	- Reid vapour pressure by ASTM D-323
SAE	- Society of Automotive Engineers
SNL-W	- super non-leaded - winter grade
TAN	- Total acid number by ASTM D-664
TBN	- total base number by ASTM D-664 or D-2896
VII	- viscosity index improver

1/ INTRODUCTION

Methanol is seen, by some as a viable future fuel for internal combustion engines in Canada. Shell Canada in association with Ford of Canada Ltd. has, since 1983, operated a small fleet of Ford Escorts specifically built to operate on near-neat methanol fuel.

This program was partially financed by both the provincial and federal governments under the Transportation Energy Management Program (TEMP) and administered by MTO and MOE.

The program was intended to evaluate the long-term durability of cars operated on fuel-methanol in comparison to gasoline. Seven 1983 Ford Escorts were operated from mid-1986 until the end of 1987. Two of the cars operated on gasoline (G 100) and the balance on fuel-methanol – in this case M85 (85% by volume methanol and 15% by volume unleaded gasoline).

2/ TEST METHODS

2.1/ Test Cars

The test vehicles in the fleet were 1983 Ford Escorts developed by the Ford Motor company to operate on a blend of 90% by volume methanol and 10% by volume unleaded gasoline. The vehicle manufacturer changed the fuel specification to 85% by volume methanol and 15% by volume high aromatic (greater than 40% by volume) winter grade unleaded gasoline prior to the initiation of this work. The specification was changed to ensure better flame visibility and a rich vapour space (under most conditions) in the vehicle's fuel tank. These vehicles were developed by Ford to operate in government service in California and, as such, were developed for its mild climate.

The cars were calibrated to meet 1983 California emission standards; 0.39 g hydrocarbon (HC)/mi (non-methane standard), 7.0 g carbon monoxide (CO)/mi, and 0.7 g nitrogen oxides (NO_x)/mi, or 0.24 g HC/km, 4.3 g CO/km, and 0.43 g NO_x/km.

The test car specifications are given in Table 1. Four vehicles were operated by Shell and three by Ford of Canada Ltd. (The cars are identified in Appendix A.)

2.2/ Test Fuels

Fourteen different test fuel blends were used between July 1986 and December 1987. Table 2 lists the typical blend specifications and inspection properties. Table 3 details the base component properties. The variations in fuel properties were not expected to impact the fuel consumption of the test cars. The test fuel blends were stored in 1000 gal. (Imp) stainless steel tanks at both Ford and Shell locations.

2.3/ Test Parameters

The major concern in this work was the durability of these methanol-fuelled vehicles under typical Canadian climate conditions.

The program was designed to evaluate the following in comparison to the two gasoline vehicles:

- engine durability via pre- and post-test engine component measurements and used-oil analysis;
- maintenance problems due to the use of near-neat methanol fuel; and
- fuel consumption of these near-neat methanol-fuelled vehicles.

2.4/ Test Configuration

The four cars at Shell were operated under normal fleet service. The normal fleet service was defined as approximately 30% urban/70% highway driving. All kilometre accumulation was via employee use of the cars both during and outside working hours.

The three cars at Ford of Canada were operated by specific employees in general service, as part of Ford's employee lease program.

The four cars at Shell, two on each of the fuels, were pre-measured. The pre-measured components included the following:

- cylinder bore diameter, both longitudinal and transverse at three locations – the top, middle, and bottom of the ring travel region (four sets);
- piston skirt diameter (four);
- ring gap, top and middle rings (four sets);
- ring weight, top and middle rings (four sets);
- rod bearing weights (four sets);
- main bearing weights (five sets);
- ring side clearances, top and middle rings (four sets);
- valve lifter heights, intake and exhaust (four sets);
- camshaft lobe heights, intake and exhaust (four sets);
- main bearing journal diameters, horizontal and vertical (five sets);
- connection rod journal diameters, horizontal and vertical, (four sets).

All four Shell cars were rated at the end of the test for the following:

- sludge deposits
 - rocker arm cover
 - front seal housing
 - oil pan
 - valve deck area
 - block underside
- varnish deposits
 - piston skirts
 - rocker arm cover
 - cylinder wall (below ring travel)
 - oil pan
- stuck components
 - rings
 - lash adjusters

- clogging
 - oil rings
 - oil screens
- intake valve deposits

All of the above were rated by Co-ordinating Research Council (CRC) methods.

Used-oil analysis was also used to monitor engine durability. The M85 cars were sampled at each drain (nominally 5000 km). The two gasoline cars were also sampled at each drain (nominally 12 000 km). Additionally, samples were taken at the midpoint of the drains on the two gasoline cars (nominally after 6000 km) during the last 30 000 km of the test.

3/ RESULTS AND DISCUSSION

3.1/ Maintenance Problems

The prior work which utilized these cars on M85 [1,2,3, and 4] also served to eliminate any major maintenance problems in both the M85 vehicles and the supporting services.

The only major fuel-related problem which occurred was preignition in the higher mileage M85 cars. All five M85 cars encountered preignition and associated damage to one or more spark plug side electrodes during the spring of 1987. It would typically happen at highway speeds of 100 km/h or more and under heavy loads (i.e., hill climbing). It was thought that due to the high mileages on these engines the air-fuel ratio metered by the carburetor at highway speeds may have become slightly leaner.

All the main fuel metering jets in the carburetors were checked and increased by a maximum of one size. Table 4 details the changes. There were no further problems evident until late 1987. Additionally, there appeared to be no measurable effect on the fuel consumption of the cars.

In late 1987, car 337, at 74 832 km, 44 318 km after rebuild, encountered severe preignition and subsequent loss of coolant. The result was two burnt valves in cylinders 1 and 3, one combustion chamber suffered some erosion between the exhaust valve seat and the spark plug hole in cylinder 3, and cracks in all combustion chambers typically between the two valve seats and/or the exhaust valve seat to the spark plug hole. Examination of the parts indicated that the initial preignition was in cylinder 3.

Car 338, at 76 498 km, 51 154 km after rebuild, started to idle roughly approximately two weeks after the failure of 337. Cylinder leakdown tests of this engine indicated valve seat leakage. The engine was then dismantled, showing the exhaust valve seat in cylinder 2 to be damaged, along with a crack from the exhaust valve seat to the spark plug hole in cylinder 1.

In early 1988, car 342, after 91 241 km, also started to idle roughly so it was then tested for cylinder leakdown. As the leakdown results looked questionable this engine was dismantled. Intake valves on cylinders 1, 3, and 4 proved to be dished, particularly cylinder 4. All cylinders showed cracks either between the valve seats or from the exhaust valve seat to the spark plug hole. At this point, it was decided to stop the program.

No fuel-related problems were encountered with the two gasoline-fuelled vehicles.

3.2/ Oil Consumption

The oil consumption for the four cars at Shell was determined by keeping track of all oil additions. The oil consumption was low, typically being less than 0.25 L per 5000 km period for both the gasoline and M85 cars. This was expected due to the good low volatility of the oil used.

3.3/ Used-Oil Analysis

Table 5 shows the oil formulation used in all seven cars. The M85 cars used a nominal drain period of 5000 km. The gasoline cars used a nominal drain period of 12 000 km.

Tables 6 through 12 inclusive, show the used-oil analysis for all seven cars over the total program. Table 13 summarizes the data per 5000 km for vehicles 335 through 338, allowing easier comparisons. The initial drain has been deleted, as it may give higher results due to ingestion of dirt during the rebuild. Drains or samples of less than 3000 km occurred when the engines failed and as there may have been other damage related to the failure mode, these have also been deleted. This allows a more valid comparison between gasoline and M85 service to be made.

The results in Table 13 show the M85 cars to have higher wear metal levels than the gasoline-fuelled cars. Aluminum is typically up to twice as high, chromium two to four times as high, copper up to twice as high, while iron, silicon, and lead are similar to the levels seen with gasoline as a fuel. The increased levels of aluminum may be partially due to the more corrosive nature of the M85 fuel to components made of aluminum alloys. The components would include the intake manifold, the cylinder head, and possibly fuel-dispensing equipment (i.e., the nozzle). They may also be due to wear of the aluminum alloy pistons. The higher level of chromium is indicative of ring wear. Copper is usually associated with thrust bearing wear in these engines; however, in this case the gasoline cars show higher main bearing weight losses than the M85 cars (see Table 16). This indicates that the copper is most likely due to corrosion of some other component.

Pentane insolubles (as shown in Tables 6 through 12) were typically less than 0.5% by mass for all cars. This is an acceptable level. Pentane insolubles include oil-insoluble matter caused by contamination and oil-insoluble resinous matter originating from oil and/or additive degradation.

Fuel dilution levels with M85, were typically <0.6% by volume, while gasoline gave levels typically <3.0% by volume. This was expected because the method used, ASTM D-322, only determines fuel insoluble in water.

Viscosities after use in both services were similar. The viscosity at 100°C changed from new by up to ± 1 cSt, while at 40°C the change was up to ± 10 cSt. This is more

than acceptable performance. Total Acid Numbers (TAN) increased by up to six numbers, with gasoline (12 000 km drains) versus by up to five numbers with M85 (5000 km drains). Total Base Numbers (TBN) dropped by up to five numbers, again the gasoline cars appeared to have higher drops, probably due to the increased mileage between oil changes. In general, the used-oil analysis results were acceptable in both services.

3.4/ Engine Ratings

Table 14 details the engine ratings for cars 335 through 338 inclusive. Deposit levels, as indicated by sludge and varnish ratings, are better in M85 fuel than gasoline. No clogged or stuck components were found on either fuel. The primary reasons for the better performance with M85 is the lower level of unstable hydrocarbons (particularly olefinic components), higher boiling-point compounds, and sulfur compounds in the fuel. A secondary reason for the improved performance would be the shorter oil-drain period used with M85.

Table 15 shows the intake valve ratings for the four Shell cars. The M85 cars gave an excellent rating of 9.0, whereas gasoline gave an acceptable rating of 8.0. Again the differences in the two fuels would be the primary reason for the improved performance with M85. Table 15 also gives the carburetor ratings. The M85 cars gave ratings of 5.8 versus 6.8 for the gasoline cars. This would be due to the lack of a carburetor cleanliness additive in the methanol portion of the M85 fuel. This is not as expected based on fuel property differences. It may indicate that the majority of the carburetor deposits come from the positive crankcase ventilation system and not thermal degradation of the fuel.

In general the deposit levels with M85 were lower than with gasoline. This was particularly evident by inspection of the combustion chamber, piston tops, and valve faces. M85 gave basically no combustion chamber deposits with some friable deposits on the piston crowns. Gasoline gave a noticeable deposit "skin" over the combustion chambers, valve faces, and piston crowns.

3.5/ Engine Wear Results

Tables 16, 17, and 18 present the engine wear results for all measured components. The M85 cars gave greater top and middle ring wear as measured by ring gap growth, ring side clearance increase, and ring weight loss. Piston skirt diameter losses were minimal with both fuels. Similarly, cylinder diameter growth at top ring reversal with both fuels was low.

Both main and connecting rod journals on the crankshaft also showed little wear with either fuel; however, bearing weight losses were 50 to 100% lower with M85. This is probably a reflection of the reduced oil-drain period used with M85 as a fuel. The faces of the thrust bearing in these engines have no overlay, the surface being a

copper alloy. The M85 cars all show this surface to be covered with a thin passivating blue or black layer. The gasoline engines show no similar layer. The most plausible explanation of this difference is that the combustion by-products of M85 that get into the sump react with the copper to form a passivating layer on the exposed copper surface.

The camshaft lobes showed less wear with M85 than with gasoline, as did the valve lifters. The lifters were all of the same batch. The camshafts were different – the gasoline engines utilized the higher output version versus the base version in the M85 cars. Examination of the worn camshafts showed visual differences in the wear patterns. This indicates that the hardness of the camshafts may have been different. This difference, in combination with the shorter oil-drain period used with M85, are the major reasons for the reduced wear of the camshaft and lifters.

Additionally, the lower level of engine deposits with M85 may also have reduced both the camshaft and bearing wear. General inspection of the engine indicated one other area of wear. The rocker arm and pivot assemblies showed much more evidence of adhesive wear with M85 than with gasoline. The wear was most likely caused by the M85 fuel actually displacing oil from the metal surfaces, possibly via a boiling mechanism during warm-up following a cold start [5].

A comparison of the wear results of these G100 and M85 Escorts with that reported in the literature with gasoline is given in Table 19. The actual data from the literature, a total of nine field trials, is given in Appendix C. This comparison assumes that wear rates are linear. The data has been appropriately changed to show wear levels at 50 000 km.

Top ring wear, as measured by ring weight loss or ring gap growth, was highest for the M85 Escorts; however, the G100 Escorts also showed high ring wear. Cylinder bore wear on both fuels is in the range of that seen in the literature with gasoline. Camshaft wear with both groups of Escorts is also higher than that reported in the literature, but the G100 Escorts, as discussed previously, are worse than the M85 Escorts. Road bearing weight losses with the M85 Escorts were within the range of that reported in the literature and were less than that seen with the G100 Escorts.

Used-oil iron levels, per 5000 km interval, were highest with the M85 Escorts, the G100 Escorts being generally similar to that quoted in the literature. Finally, varnish and sludge levels were lowest with the M85 cars, the G100 versions again being generally similar to that quoted in the literature.

The above comparisons should only be used to draw general conclusions regarding the use of M85 versus gasoline, as engine wear and deposits are a function of engine design, vehicle service, oil quality, drain interval, and ambient conditions. The most valid comparison that can be made is between the two equivalent groups of Escorts operated on the two fuels in question.

3.6/ Engine Durability

The results show better engine cleanliness, reduced camshaft, lifter, and bearing wear with M85 fuel. However, these conclusions must be tempered with the reduced oil-drain period of 5000 km used versus that used with gasoline – namely 12 000 km. Ring wear is the major area of concern with M85 fuel. Other areas such as the rocker arm pivot assemblies may also require some changes to give acceptable performance with M85 fuel.

The poorer level of carburetor cleanliness with M85 fuel points to either a requirement for a detergent additive in the fuel or possibly changes to the positive crankcase ventilation system to match it to the higher compression of the M85 version of this engine.

The damage due to preignition is the other major area of concern with these engines operated on M85 fuel. The Escort engine was not designed for a compression ratio of 11.8:1. This change in compression ratio will significantly increase the thermal loading of the cylinder head. This increase in stress is a partial cause of the head cracks that developed; however, the poor resistance of M85 fuel to preignition is the major cause. The combustion chamber design could be changed in materials or configuration to allow the use of such a fuel which has poor preignition resistance.

3.7/ Fuel Consumption

Fuel and energy consumption of the four Shell cars is summarized in Tables 20 and 21, and Figures 14 and 15. Overall, the energy consumption of the two M85 cars is lower by about 10% compared to the two gasoline cars. The gasoline cars show no real trend versus time of year, however, the two M85 cars show lower energy consumption in the summer and higher energy consumption in the winter. The actual M85 fuel consumption figures are similar to those found in "Field Experience with Methanol Vehicles: Future Design Considerations." [6]

4/ CONCLUSIONS

- 1/ The candidate oil gave acceptable performance with both fuels.
- 2/ Compared with gasoline and a 12 000 km oil drain interval, the use of M85 fuel and a 5000 km oil drain interval gave
 - better engine cleanliness
 - reduced combustion chamber deposits
 - reduced camshaft, lifter, and bearing wear
 - increased ring wear
 - poorer carburetor cleanliness
- 3/ Used-oil analysis wear metal levels of aluminum, copper, and chromium when compared on an equivalent mileage basis, are higher with M85 fuel than with gasoline.
- 4/ Measured oil consumption was low.
- 5/ Preignition and associated damage is the major problem area with M85 fuel in this engine type.
- 6/ Energy consumption of the M85 cars was lower than the gasoline cars.

5/ RECOMMENDATIONS

For near-neat methanol fuels such as M85 to be viable in colder climates such as those occurring in Canada, further improvements to engine durability (to reduce preignition problems) and ring wear are required. These improvements would possibly include hardware, oil formulation, or even fuel property changes.

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Table 1/ Test Vehicle Specifications

Model	1983 Ford Escort
Body Styles	4-door hatchback – station wagon
Engine Type	OHC, in-line 4 cylinder
Bore x Stroke	80 x 79 mm
Capacity	1.6 L
Compression Ratio	11.8:1
Power Output	85 hp @ 5200 rpm
Top Ring Type	Bare-faced, chrome-plated
Head Gasket	1984 type – stainless steel fire rings
Camshaft Type	base
Distributor	modified spark curve (vs. gasoline version)
Spark Plug Type	AGSF12C
Fuel System Specifications	– stainless steel fuel tank – stainless steel fuel lines – nickel-plated in-tank sending unit – nylon-coated fuel tank straps – nickel-plated fuel pump – nickel-plated, recalibrated carburetor – new carburetor spacer with electrical heating unit

Table 2/ Typical Fuel Blend Properties

BLEND	SUMMER ¹	SUMMER ²	WINTER ³
Inspection Properties			
Density, kg/L	0.788	0.786	0.786
ASTM D-86 Distillation			
IBP °C	47	47	41
10%, °C	63	62	61
50%, °C	65	65	64
90%, °C	66	66	64
EP, °C	170	167	65
C, % by mass	44.3	44.4	44.4
H, % by mass	12.7	12.6	12.6
O, % by mass	43.0	43.0	43.0
RVP (dry) kPa, (psi)	46 (6.7)	60 (8.7)	70 (10.2)
Water Content, mg/kg	128	150	130
Cl, mg/kg	<1.0	<1.0	<1.0
Energy Content MJ/L (net on LH value)	18.2	18.2	18.2

1 - Contains Premium Unleaded

2 - Contains Regular Unleaded

3 - Contains High Vapour Pressure Premium Unleaded

Table 3/ Base Component Inspection Properties

COMPONENT	REGULAR UNLEADED	PREMIUM UNLEADED	PREMIUM UNLEADED (Feb./87 & Mar./87)	MeOH (TYP.)
Inspection Properties				
Density, kg/L	0.743	0.750	0.737	0.796
ASTM D-86 Distillation				
IBP, °C	30	30	26	65
10%, °C	37	45	27	65
50%, °C	99	112	106	65
90%, °C	164	165	160	65
EP, °C	205	219	208	68
C, % by mass	86.8	86.8	86.6	37.5
H, % by mass	13.2	13.2	13.4	12.5
O, % by mass	-	-	-	50.0
RVP (dry), kPa (psi)	89.3 (12.8)	69.0 (10.0)	102.0 (14.8)	30.2 (4.4)
Water Content, mg/kg	35	45	51	194
Cl, mg/kg	<1.0	-	-	<1.0
Energy Content				
(book value)				
(net or LH value) MJ/L	32.0	32.0	32.0	15.9

Table 4/ Carburetor Jet Size Changes

CAR NO.	JET LOCATION	INITIAL SIZE ¹	FINAL SIZE
337	Primary	115	120
	Secondary	160	165
338	Primary	125	<u>125</u> ²
	Secondary	160	165
342	Primary	125	<u>125</u>
	Secondary	160	165
343	Primary	120	125
	Secondary	160	165
344	Primary	125	<u>125</u>
	Secondary	160	165

¹ - Metric drill size of jet orifice

² - Underlined sizes were not changed

Table 5/ Lubricant Specifications

Viscosity @ 40°C, cSt	62.5
@ 100°C, cSt	10.5
@ -20°C, cP	3300
TANe, D-664 mg KOH/g	2.3
TBNe, D-664 mg KOH/g	13.6
TBNe, D-2896 mg KOH/g	13.5
Sulphated Ash, % by mass	1.58
Mg, % by mass	0.22
Ca, % by mass	0.12
Zn, % by mass	0.16
P, % by mass	0.13

Table 6/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 335

OIL GRADE	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	---	35935	47909	59989	65976	72097	79037	84251	90342			
TANe mg KOH/g D-664	2.3	3.5	6.5	6.3	---	5.5	---	6.4	8.4			
TBNe mg KOH/g D-664	13.6	8.7	---	10.1	---	12.0	---	10.8	10.6			
TBNe mg KOH/g D-2896	13.5	10.5	13.3	13.8	---	15.1	---	13.4	13.7			
Fuel Dilution D-332	0.0	1.6	1.2	1.0	---	1.0	---	3.1	---			
Visc. @ 100°C	10.5	9.6	11.1	11.2	10.6	10.8	10.9	11.1	9.8			
Visc. @ 40°C	62.5	55.2	69.7	72.9	65.1	69.3	67.5	70.3	57.3			
Pentane Insol. D-893	0.0	0.6	0.1	0.1	---	0.1	---	0.1	0.1			
Al ppm	0	13	7	6	7	9	6	8	11			
Cr ppm	0	11	6	4	2	3	3	4	3			
Cu ppm	0	21	8	8	4	9	8	13	11			
Fe ppm	0	74	75	78	41	74	52	80	71			
Pb ppm	0	50	43	38	27	51	28	45	22			
Si ppm	0	68	18	13	11	13	11	12	11			
km on Oil	0	11835	11974	12080	5987	6121	6940	5214	6091			
Date of Change	0	Nov 86	Feb 87	June 87	July 87	Sept 87	Oct 87	Nov 87	Jan 88			
Fuel Type		G100	G100	G100	G100	G100	G100	G100	G100			
Comments		Initial Drain	Drain	Drain	Sample	Drain	Sample	Drain	Drain			

Table 7/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 336

OIL GRADE	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	---	22222	33401	45691	51691	58183	64669	69890	74988	
TANe mg KOH/g D-664	2.3	5.8	7.3	7.7	---	4.7	---	6.4	8.8	
TBNe mg KOH/g D-664	13.6	5.1	9.5	8.2	---	10.1	---	10.0	8.6	
TBNe mg KOH/g D-2896	13.5	7.3	11.3	12.3	---	13.1	---	12.8	12.2	
Fuel Dilution D-332	0.0	2.0	1.8	3.6	---	1.1	---	2.5	2.7	
Visc. @ 100°C	10.5	10.8	10.5	9.8	10.4	12.4	9.1	11.4	7.8	
Visc. @ 40°C	62.5	68.7	71.5	59.8	63.1	85.2	49.1	74.3	39.2	
Pentane Insol. D-893	0.0	4.4	0.4	0.3	---	0.4	---	0.2	0.1	
Al ppm	0	14	10	8	5	8	6	8	6	
Cr ppm	0	14	9	8	3	8	6	10	5	
Cu ppm	0	27	12	13	10	20	12	18	21	
Fe ppm	0	177	125	159	56	149	76	156	73	
Pb ppm	0	67	47	59	27	158	52	79	24	
Si ppm	0	77	20	15	11	16	16	17	10	
km on Oil	0	13114	11179	12290	6000	6492	6486	5221	5098	
Date of Change	0	Oct 86	Feb 87	May 87	June 87	Aug 87	Oct 87	Nov 87	Jan 88	
Fuel Type	G100	G100	G100	G100	G100	G100	G100	G100	G100	
Comments	Initial Drain	Drain	Drain	Drain	Sample	Drain	Sample	Drain	Drain	

Table 8/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 337

OIL GRADE	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	---	35493	40699	46389	50837	55724	60586	65917	71322	74832		
TANe mg KOH/g D-664	2.3	---	7.4	4.1	5.0	6.3	6.4	6.3	3.5	6.5		
TBNe mg KOH/g D-664	13.6	---	11.0	---	10.9	9.2	10.0	10.1	11.5	10.3		
TBNe mg KOH/g D-2896	13.5	---	12.8	12.1	13.2	12.0	13.1	8.8	13.4	13.1		
Fuel Dilution D-332	0.0	0.4	1.2	1.4	0.2	0.2	0.2	0.2	0.9	---		
Visc. @ 100°C	10.5	9.9	9.6	FD*	10.1	10.2	10.5	10.7	---	10.4		
Visc. @ 40°C	62.5	60.3	57.9	54.5	62.6	62.5	65.0	67.3	62.5	65.1		
Pentane Insol. D-893	0.0	0.4	0.6	0.5	0.1	0.1	0.1	0.2	0.4	0.1		
Al ppm	0	15	11	8	9	7	7	12	11	10		
Cr ppm	0	19	10	8	13	18	16	24	20	12		
Cu ppm	0	21	12	16	10	10	10	10	9	10		
Fe ppm	0	87	74	64	52	50	56	83	75	57		
Pb ppm	0	87	65	29	24	20	19	28	21	18		
Si ppm	0	63	17	13	11	10	11	13	12	16		
km on Oil	0	4979	5206	5690	4248	5087	4862	5331	5405	3510		
Date of Change	0	Oct 86	Dec 86	Feb 87	Mar 87	April 87	May 87	July 87	Sept 87	Nov 87		
Fuel Type		M85	M85	M85	M85	M85	M85	M85	M85	M85		
Comments		Initial Drain	Drain	Drain	Drain	Drain	Drain	Drain	Drain	Drain		

*Invalid because of fuel dilution

Table 9/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 338

OIL GRADE	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	—	35493	40637	45290	50631	55753	61129	66310	71203	76498	81404	81745	
TANe mg KOH/g D-664	2.3	—	7.2	2.8	3.8	2.6	3.5	3.2	5.7	4.2	3.6	4.0	
TBNe mg KOH/g D-664	13.6	—	11.3	12.5	10.6	11.8	11.9	12.0	12.8	12.6	11.7	12.7	
TBNe mg KOH/g D-2896	13.5	—	11.5	12.7	12.6	14.0	11.8	14.0	14.8	15.3	13.1	13.3	
Fuel Dilution D-332	0.0	0.6	0.8	1.2	0.3	0.6	0.4	0.4	0.6	0.6	10.1	10.1	
Visc. @ 100°C	10.5	9.9	9.6	FD*	9.9	FD*	10.3	10.3	11.2	9.7	10.1	10.0	
Visc. @ 40°C	62.5	60.0	57.6	54.5	59.4	59.5	63.0	63.4	71.2	61.2	61.4	61.2	
Pentane Insol. D-893	0.0	0.3	0.4	0.5	0.3	0.3	0.1	0.1	0.1	0.3	0.4	0.1	
Al ppm	0	17	11	9	6	5	6	5	5	6	6	3	
Cr ppm	0	20	10	13	6	3	5	4	3	5	7	1	
Cu ppm	0	28	16	15	9	6	4	2	2	3	7	1	
Fe ppm	0	99	72	85	50	38	55	46	41	53	71	15	
Pb ppm	0	112	73	29	18	13	12	12	10	11	12	2	
Si ppm	0	62	8	13	10	10	11	9	9	9	10.1	7	
km on Oil	0	5413	5139	4653	5341	5122	5376	5181	4893	5295	4906	341	
Date of Change	0	Oct 86	Dec 86	Feb 87	Mar 87	May 87	July 87	Aug 87	Sept 87	Oct 87	Nov 87	Dec 87	
Fuel Type		M85	M85	M85	M85	M85	M85	M85	M85	M85	M85	M85	
Comments		Initial	Drain	Drain	Drain	Drain	Drain	Drain	Drain	Drain	Drain	Drain	

*Invalid because of fuel dilution

Table 10/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 342

Oil Grade	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	—	63589	69612	77269	82299	88403	91241
TANe mg KOH/g D-664	2.3	5.8	4.5	4.1	3.2	3.6	2.3
TBNe mg KOH/g D-664	13.6	10.7	9.9	10.5	13.2	6.7	—
TBNe mg KOH/g D-2896	13.5	12.7	11.7	14.4	14.2	5.9	13.6
Fuel Dilution D-332	0.0	1.0	1.4	1.0	0.8	0.6	0.6
Visc. @ 100°C	10.5	9.8	9.5	10.2	10.0	9.9	—
Visc. @ 40°C	62.5	58.8	55.6	62.1	60.0	59.5	57.0
Pentane Insoluble, D-893	0.0	0.5	0.4	0.4	0.3	0.4	0.4
Al ppm	0	12	5	11	7	7	4
Cr ppm	0	11	9	11	6	7	4
Cu ppm	0	18	32	15	8	17	15
Fe ppm	0	77	50	69	42	57	29
Pb ppm	0	43	53	38	17	24	13
Si ppm	0	4	7	10	9	9	8
km on Oil	0	5516	6023	7657	5030	6104	2838
Date of Change	0	Oct 86	Mar 87	July 87	Sept 87	Dec 87	Feb 88
Fuel Type		M85	M85	M85	M85	M85	M85
Comments		Initial Drain	Drain	Drain	Drain	Drain	Drain

Table 11/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 343

Oil Grade	10W30	10W30
km	68608	73861
TANe mg KOH/g D-664	3.9	5.1
TBNe mg KOH/g D-664	11.2	9.9
TBNe mg KOH/g D-2896	12.4	12.3
Fuel Dilution D-332	0.6	---
Visc. @ 100°C	FD*	10.3
Visc. @ 40°C	57.2	62.4
Pentane Insoluble D-893	0.3	0.4
Al ppm	3	6
Cr ppm	9	9
Cu ppm	15	16
Fe ppm	47	56
Pb ppm	24	19
Si ppm	15	11
km on Oil	7473	5253
Date of Change	Apr 87	Dec 87
Fuel Type	M85	M85
Comments	Initial Drain	Drain

*Invalid because of fuel dilution

Table 12/ Ford/Shell M85 Durability Trial

Used-Oil Analysis Car 344

Oil Grade	10W30	10W30	10W30	10W30	10W30	10W30
km	-----	62116	67012	74260	81830	87879
TANe mg KOH/g D-664	2.3	3.3	3.7	3.3	3.1	3.7
TBNe mg KOH/g D-664	13.6	10.3	----	11.2	11.2	11.4
TBNe mg KOH/g D-2896	13.5	13.6	----	13.9	14.0	14.3
Fuel Dilution D-332	0.0	0.4	----	0.4	3.2	0.7
Visc. @ 100°C	10.5	10.1	9.7	10.4	10.7	10.5
Visc. @ 40°C	62.5	62.3	57.7	64.3	66.3	64.0
Pentane Insol. D-893	0.0	0.3	----	0.3	0.1	0.3
Al ppm	0	8	8	7	10	6
Cr ppm	0	14	12	8	7	4
Cu ppm	0	9	21	20	14	19
Fe ppm	0	39	62	70	69	57
Pb ppm	0	21	35	32	29	20
Si ppm	0	7	10	11	11	10
Km on Oil	0	5516	4896	7248	7570	6049
Date of Change	0	Oct 86	Feb 87	May 87	Aug 87	Nov 87
Fuel Type		M85	M85	M85	M85	M85
Comments		Initial Drain	Drain	Drain	Drain	Drain

Table 13/ Used-Oil Analyses Per 5000 km Summary

ppm/5000 km Average

FUEL	CAR NO.	Al	Cr	Cu	Fe	Pb	Si
Gasoline	335	4.6	1.9	4.9	37.1	19.3	7.1
	336	4.1	3.8	9.2	60.5	32.6	8.6
	Ave.	4.4	2.9	7.1	48.8	26.0	7.9
M85	337	9.7	15.5	11.2	65.5	28.3	13.5
	338	6.7	6.5	7.5	58.2	22.1	10.1
	Ave.	8.2	11.0	9.4	61.9	25.2	11.8
M85	342	6.2	6.7	16.9	45.2	25.7	8.6
	344	6.1	6.4	15.0	51.1	23.4	8.3
	Ave.	6.2	6.6	16.0	48.2	24.6	8.5

Table 14/ Engine Ratings

	GASOLINE			M85		
Car No.	335	336	Ave.	337	338	Ave.
Sludge Deposits						
Rocker Arm Cover	9.50	9.00	9.25	9.75	9.75	9.75
Front Seal Housing	9.50	9.67	9.59	9.75	9.80	9.78
Oil Pan	9.32	9.41	9.37	9.64	9.70	9.67
Valve Deck	9.63	9.63	9.63	9.75	9.75	9.75
Block Underside	<u>9.70</u>	<u>9.67</u>	<u>9.69</u>	<u>9.75</u>	<u>9.75</u>	<u>9.75</u>
Average Sludge	9.53	9.48	9.50	9.73	9.75	9.74
Varnish Deposits						
Piston Skirt	7.10	7.16	7.13	9.43	9.23	9.33
Rocker Arm Cover	5.96	3.72	4.84	8.98	8.83	8.91
Cylinder Wall	7.11	7.39	7.25	8.81	8.45	8.63
Oil Pan	<u>8.28</u>	<u>5.51</u>	<u>6.90</u>	<u>9.10</u>	<u>8.41</u>	<u>8.76</u>
Average Varnish	7.11 8.91	5.95	6.53	9.08	8.73	8.91
Clogging						
Oil Ring, %	0.00	0.00	0.00	0.00	0.00	0.00
Oil Screen, %	0.00	0.00	0.00	0.00	0.00	0.00
Stuck Components						
Comp. Rings, No.	0.00	0.00	0.00	0.00	0.00	0.00
Oil Rings, No.	0.00	0.00	0.00	0.00	0.00	0.00
Lash Adjuster Bodies, No.	0.00	0.00	0.00	0.00	0.00	0.00
N.B. 10 = CLEAN						

Table 15/ Engine Valve and Carburetor Ratings

Car No.	Gasoline			M85		
	335	336	Ave.	337	338	Ave.
Intake Valve Deposits (Ratings)						
1	7.75	7.75	7.75	9.25	8.75	9.00
2	8.00	8.25	8.13	9.25	8.75	9.00
3	8.00	8.00	8.00	9.25	8.75	9.00
4	<u>8.00</u>	<u>8.00</u>	<u>8.00</u>	<u>9.25</u>	<u>8.75</u>	<u>9.00</u>
Average	7.94	8.00	7.97	9.25	8.75	9.00
Carburetor Cleanliness (Ratings)						
Primary	8.8	7.1	8.0	6.2	5.2	5.7
Secondary	<u>5.5</u>	<u>5.9</u>	<u>5.7</u>	<u>6.2</u>	<u>5.7</u>	<u>6.0</u>
Average	7.2	6.5	6.8	6.2	5.5	5.8

N.B. 10 = Clean

Table 16/ Engine Wear Results - Dimensional

Car No.	GASOLINE				M85	
	335	336	Ave.	337	338	Ave.
Cylinder Diameter Longitudinal, in.	0.0005	0.0008	0.0007	0.0007	0.0007	0.0007
Transverse, in.	0.0003	0.0006	0.0005	0.0004	0.0006	0.0005
Piston Skirt Diameter, in.	0.0005	0.0004	0.0004	0.0004	0.0002	0.0003
Ring Gap Growth (Top), in.	0.0080	0.0093	0.0086	0.0145	0.0065	0.0105
(Middle), in.	0.0035	0.0037*	0.0036	0.0060	0.0048	0.0054
Ring Side Clear. (Top), in.	0.0010	0.0009	0.0009	0.0016	0.0018	0.0017
(Middle) in.	0.0005	0.0008	0.0006	0.0001	0.0005	0.0003
Camshaft Lobe (I), in.	0.0050	0.0074	0.0062	0.0023	0.0040	0.0031
(E), in.	0.0058	0.0074	0.0066	0.0017	0.0030	0.0024
Valve Lifter Height (I), in.	0.0045	0.0067	0.0056	0.0027	0.0028	0.0027
(E), in.	0.0050	0.0055	0.0052	0.0030	0.0028	0.0029
Journals - Connecting Rod, in.	0.0002	0.0006	0.0004	0.0001	0.0004	0.0002
Main, in.	0.0001	0.0000	0.0001	0.0010	0.0001	0.0005
Kilometre Travelled	66242	65880		44318	51660	

*Cylinder 2 - Broken Ring

Table 17/ Engine Wear Results – Dimensional (Metric)

Car No.	GASOLINE				M85	
	335	336	Ave.	337	338	Ave.
Cylinder Diameter	13.5	20.3	16.9	16.9	16.9	16.9
Longitudinal, μm						
Transverse, μm	6.8	16.1	11.4	9.3	15.2	12.3
Piston Skirt Diameter, μm	11.4	10.8	11.1	8.9	4.4	6.7
Ring Gap Growth	203.2	235.0	219.1	368.3	165.1	266.7
(Top), μm						
(Middle), μm	88.9	93.1*	91.0	152.4	120.7	136.5
Ring Side Clear.	25.4	22.2	23.8	41.3	44.5	42.9
(Top), μm						
(Middle), μm	12.7	19.1	15.9	3.2	12.7	7.9
Camshaft Lobe	127.6	187.3	157.5	57.2	102.2	79.7
(I), μm						
(E), μm	146.1	188.0	167.0	43.8	76.2	60.0
Valve Lifter Height	113.0	170.8	141.9	69.2	69.9	69.5
(I), μm						
(E), μm	125.7	139.7	132.7	74.9	70.5	72.7
Journals – Connecting Rod μm	5.1	14.0	9.5	1.9	9.5	5.7
Main, μm	3.0	0.5	1.8	24.9	1.5	13.2
Kilometre Travelled	66242	65880		44318	51660	

*Cylinder 2 – Broken Ring

Table 18/ Engine Wear Results - Weight

Car No.	GASOLINE				M85	
	335	336	Ave.	337	338	Ave.
Ring Weight Cleaned Loss	(Top), g	0.2837	0.2582	0.2997	0.2903	0.2950
	(Middle), g	0.0441	0.0584	0.0757	0.0502	0.0629
Rod Bearing Weight Loss	(Top), g	0.0352	0.1384	0.0421	0.0142	0.0281
	(Bottom), g	0.0317	0.0281	0.0217	0.0224	0.0221
	(Both), g	0.0669	0.1665	0.0638	0.0366	0.0502
Main Bearing Weight Loss	(Top), g	0.0767	0.0918	0.0605	0.0545	0.0575
	(Bottom), g	0.0440	0.0249	0.0216	0.0183	0.0200
	(Both), g	0.1207	0.1167	0.0821	0.0728	0.0775
Kilometre Travelled	66242	65880		44318	51660	

Table 19/ A Comparison with Reported Gasoline Wear Results

PARAMETER	Present Study ²		
	G100 Expected Results ¹ @ 50 000 km	G100 Results @ 50 000 km	M85 Results @ 50 000 km
Carn Wear, μm	50 max. 19 typ.	123 ave.	73 ave.
Sludge (10 = clean)	9.5+	9.6 ave.	9.7 ave.
Varnish (10 = clean)	7.3 min. 8.8 typ.	7.3 ave.	8.9 ave.
Top Ring Weight Loss, mg	26.2 max.	195 ave.	307 ave.
Top Ring Gap Growth, μm	115 max.	166 ave.	278 ave.
Cylinder Bore Wear, μm	38 max. 3.3 typ.	11 ave.	16 ave.
Rod Bearing Weight Loss, mg	77 max. 30 typ.	89 ave.	52 ave.
Used-Oil Level, ppm Fe (per 5000 km)	23 max.	49 ave.	55 ave.

¹ - Based on Appendix C - linear wear rates assumed

² - Based on a 50 000 km level assuming linear wear rates

Table 20/ Fuel Consumption – Gasoline Car

CAR 335 – GASOLINE

DATE	MILEAGE (km)	MJ/100 KM	L/100 km	MPG(imp.)	MPG(U.S.)
July 86	1342	319.5	10.0	28.3	23.6
Sept. 86	2003	295.2	9.2	30.6	25.5
Nov. 86	2972	307.3	9.6	29.4	24.5
Jan. 87	3295	304.0	9.5	29.9	24.9
Mar. 87	2208	303.2	9.5	29.8	24.8
May 87	1994	278.6	8.7	32.4	27.0
July 87	3594	291.2	9.1	31.1	25.9
Sept. 87	3395	281.4	8.8	32.1	26.8
Nov. 87	3844	296.1	9.3	30.5	25.4

CAR 336 – GASOLINE

July 86	1952	272.1	8.5	33.2	27.7
Sept. 86	2501	280.2	8.8	32.3	26.9
Nov. 86	3768	275.3	8.6	32.8	27.3
Jan. 87	2516	297.6	9.3	30.3	25.2
Mar. 87	3490	280.8	8.8	32.2	26.8
May 87	1449	295.5	9.2	30.6	25.5
July 87	3734	291.2	9.1	31.1	25.9
Sept. 87	3218	301.3	9.4	30.0	25.0
Nov. 87	3006	313.8	9.8	28.8	24.0

Table 21/ Fuel Consumption – M85 Cars

CAR 337 – M85

DATE	MILEAGE (km)	MJ/100 KM	L/100 km	MPG(Imp.)	MPG(U.S.)
July 86	567	240.7	13.2	21.4	17.8
Sept. 86	1543	277.2	15.2	18.5	15.4
Nov. 86	1627	300.4	16.5	17.1	14.3
Jan. 87	2218	282.1	15.5	18.2	15.2
Mar. 87	4333	267.6	14.7	19.2	16.0
May 87	3491	238.3	13.1	21.6	18.0
July 87	2636	260.3	14.3	19.7	16.4
Sept. 87	1800	285.1	15.7	18.0	15.0

CAR 338 – M85

July 86	724	246.4	13.5	20.9	17.4
Sept. 86	1563	266.7	14.7	19.3	16.1
Nov. 86	1612	293.0	16.1	17.5	14.6
Jan. 87	1964	291.2	16.0	17.7	14.7
Mar. 87	4721	262.9	14.4	19.6	16.3
May 87	1440	247.6	13.6	20.8	17.3
July 87	2374	236.6	13.0	21.7	18.1
Sept. 87	5444	221.0	12.1	23.3	19.4
Nov. 87	2280	264.2	14.5	19.5	16.2

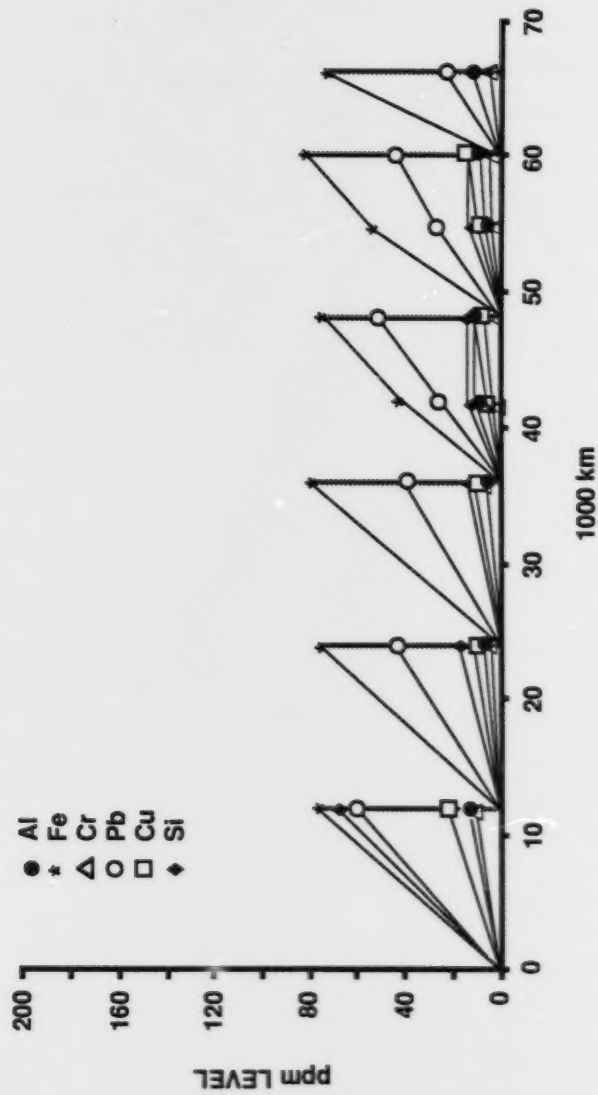


Figure 1/ Used-Oil Analysis, Car 335

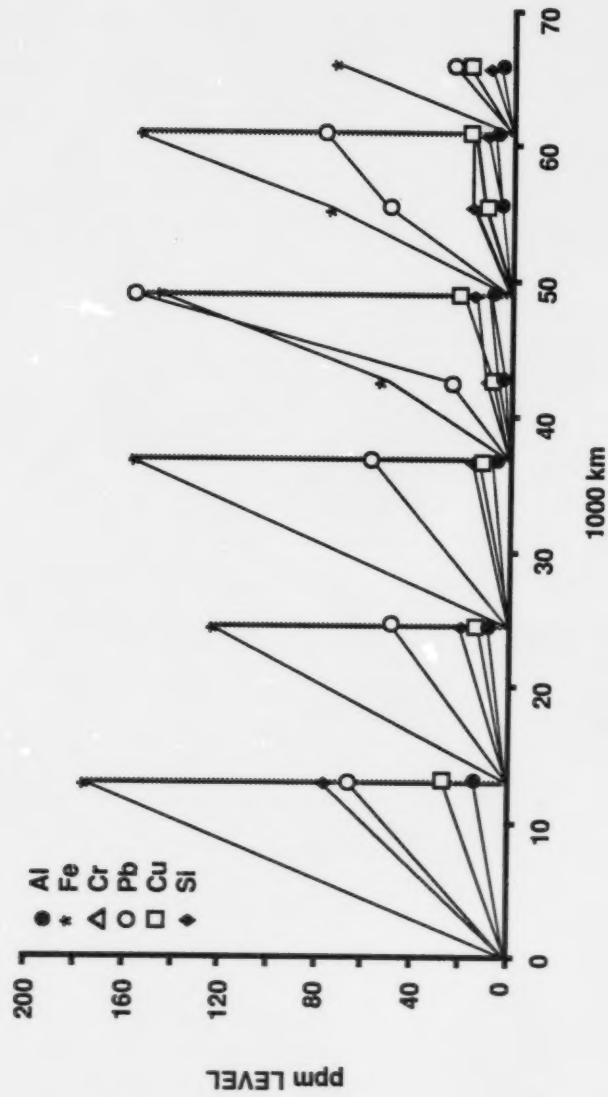


Figure 2/ Used-Oil Analysis, Car 336

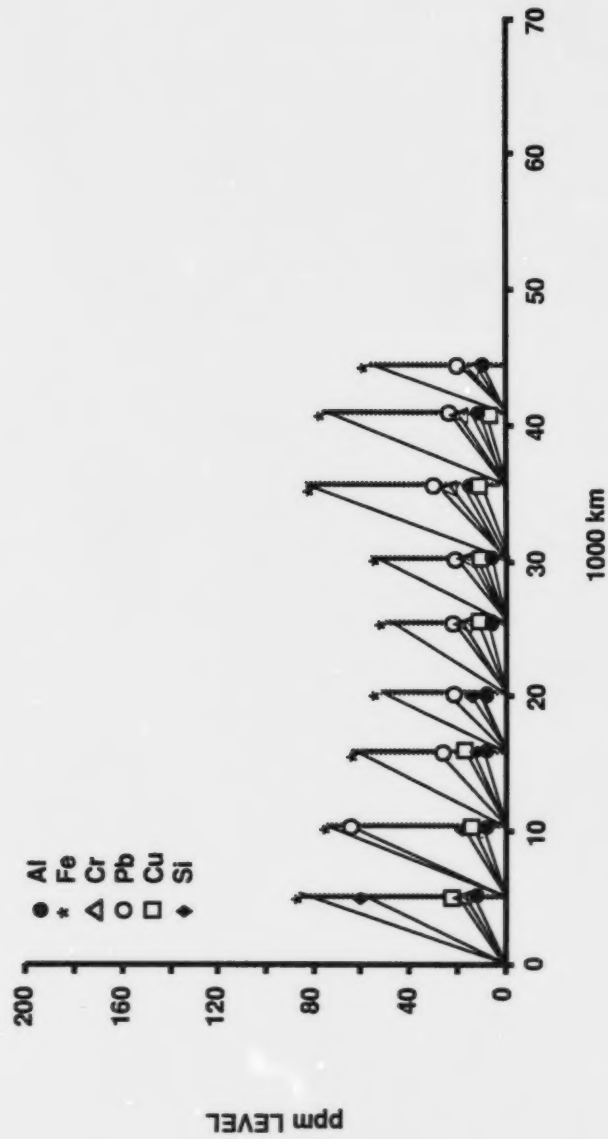


Figure 3/ Used-Oil Analysis, Car 337

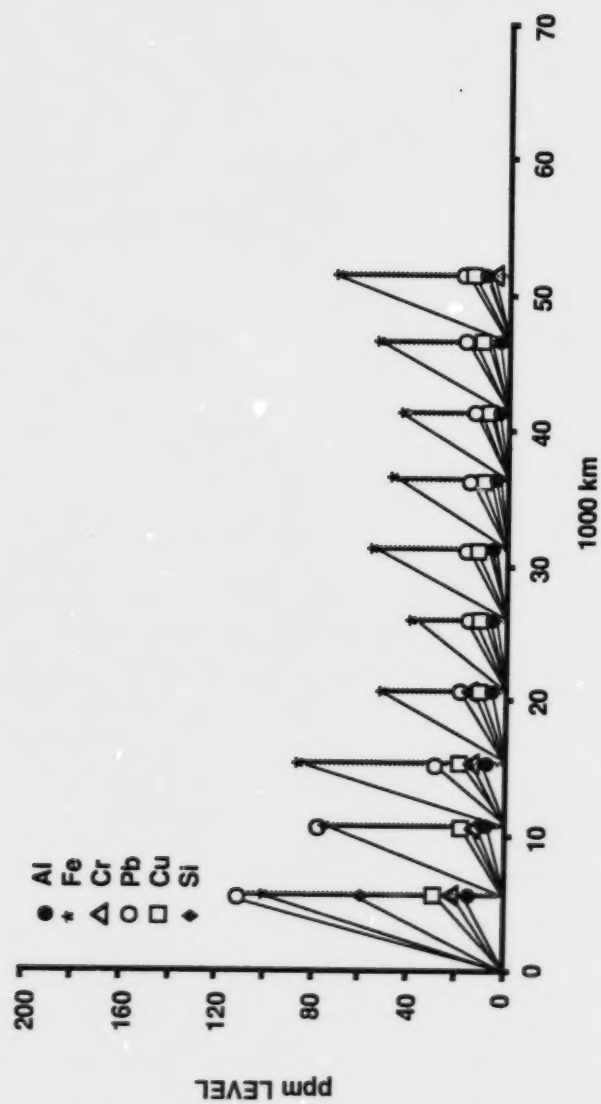


Figure 4/ Used-Oil Analysis, Car 338

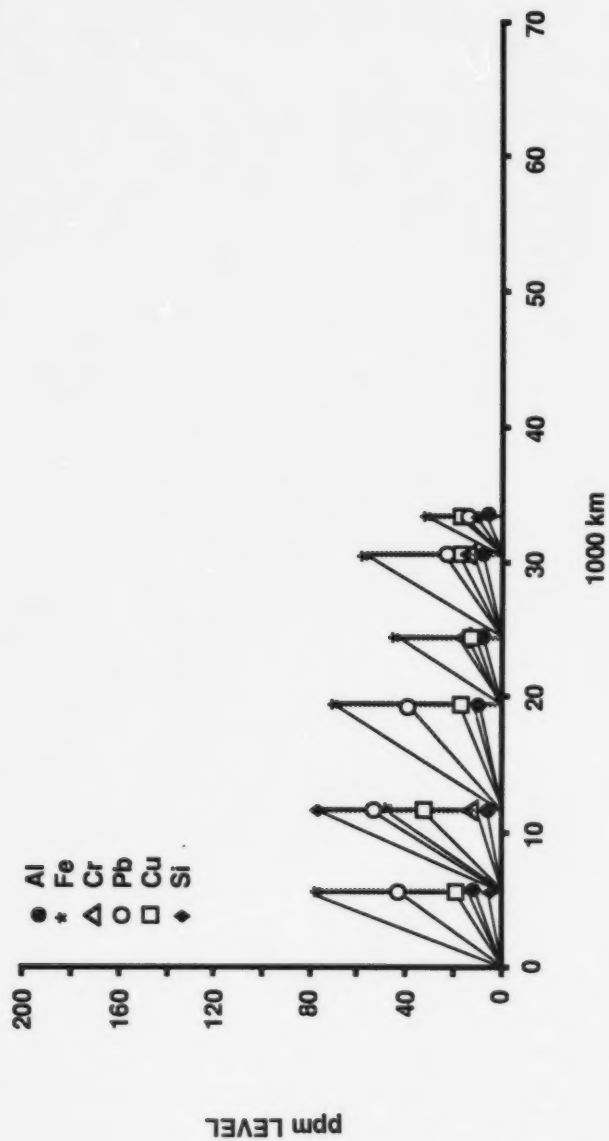


Figure 5/ Used-Oil Analysis, Car 342

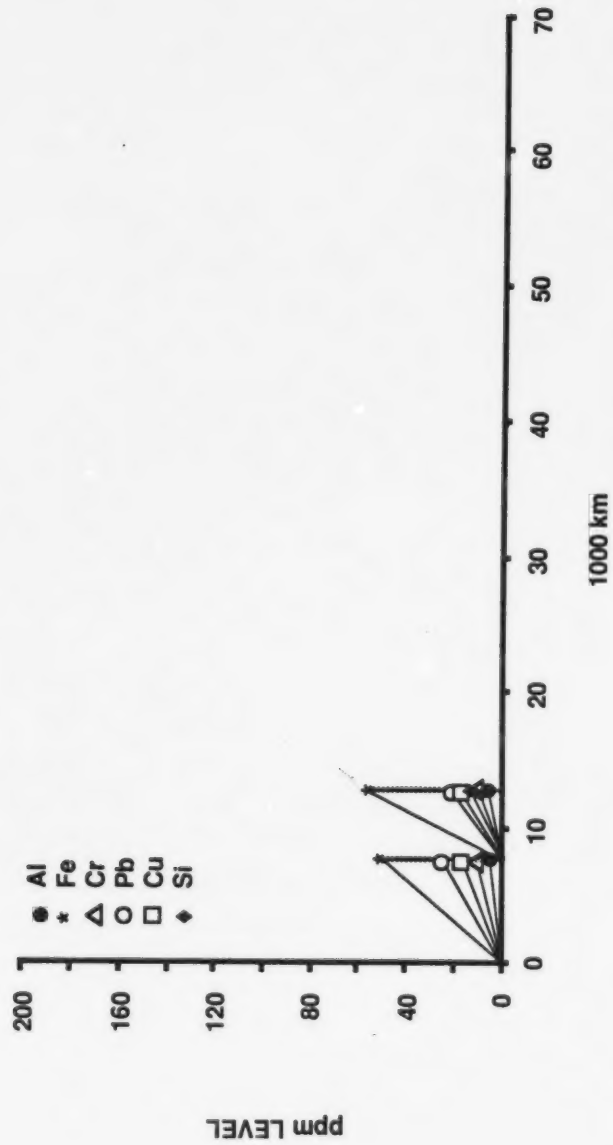


Figure 6/ Used-Oil Analysis, Car 343

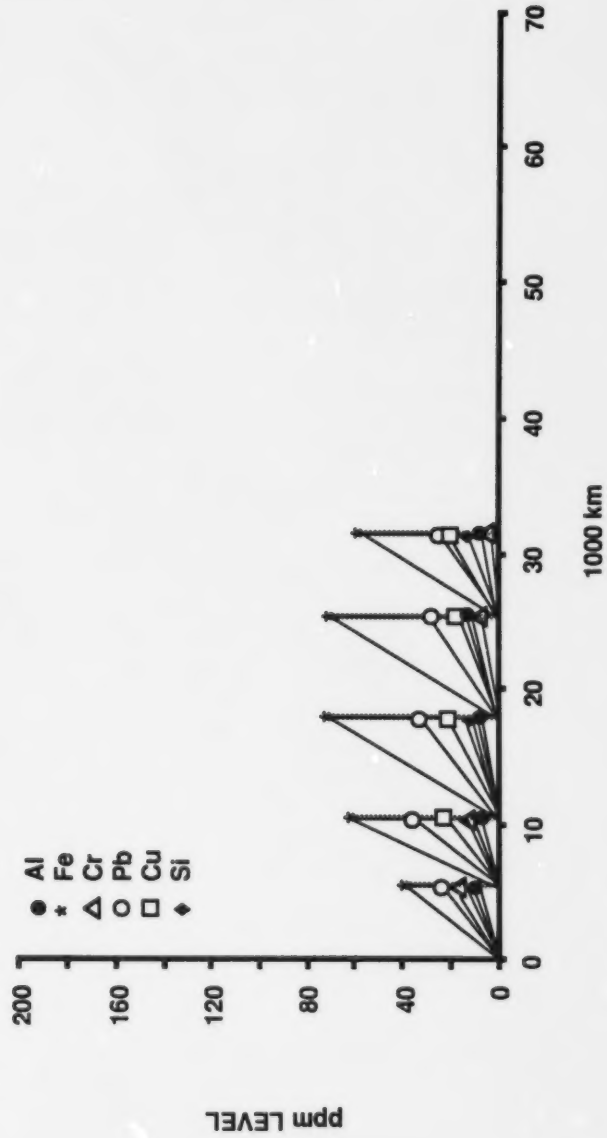


Figure 7/ Used-Oil Analysis, Car 344

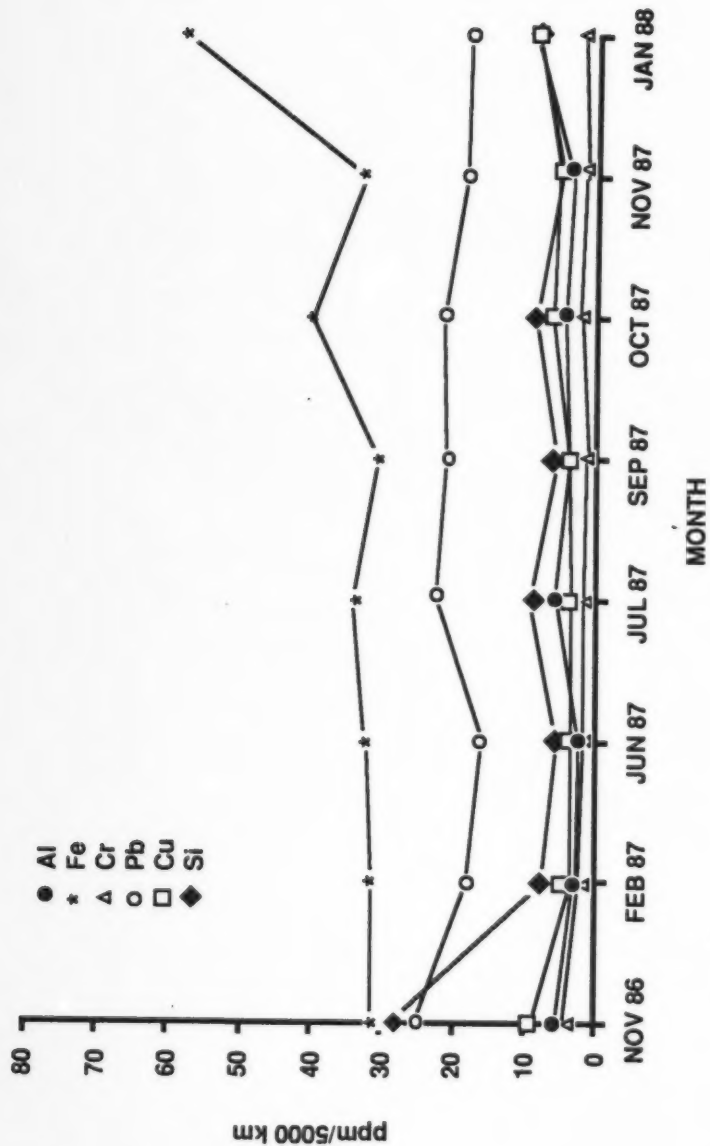


Figure 8/ Used-Oil Analysis, Car 335

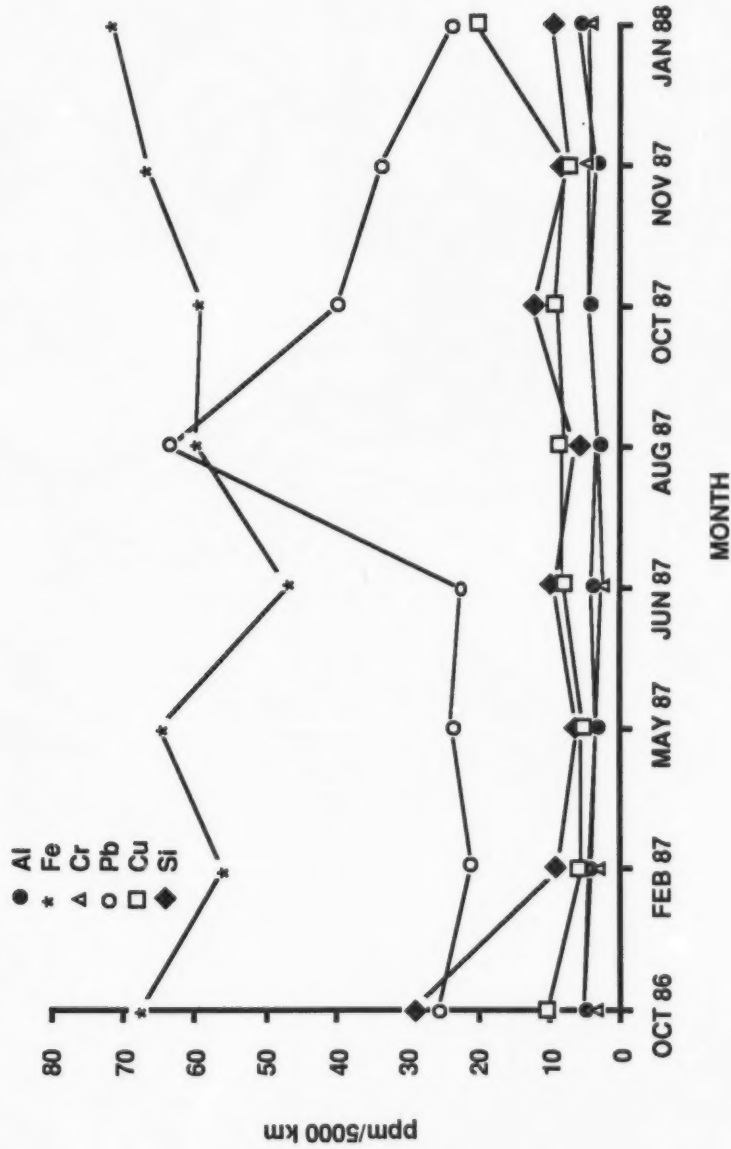


Figure 9/ Used-Oil Analysis, Car 336

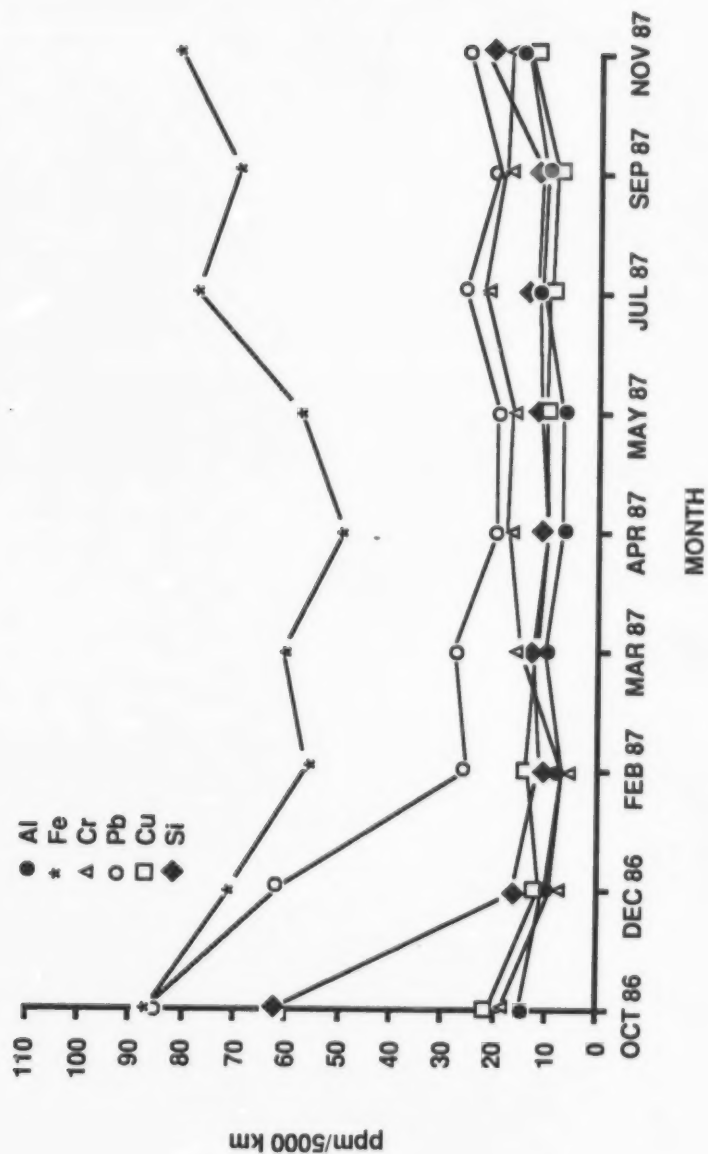


Figure 10/ Used-Oil Analysis, Car 337

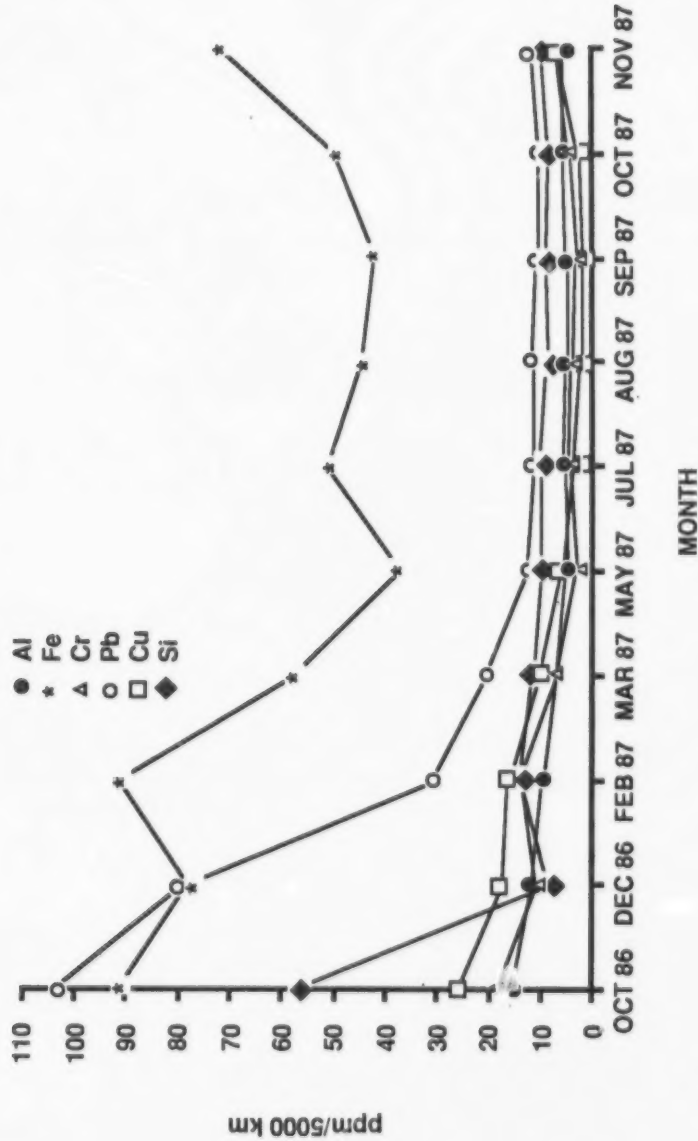


Figure 11/ Used-Oil Analysis, Car 338

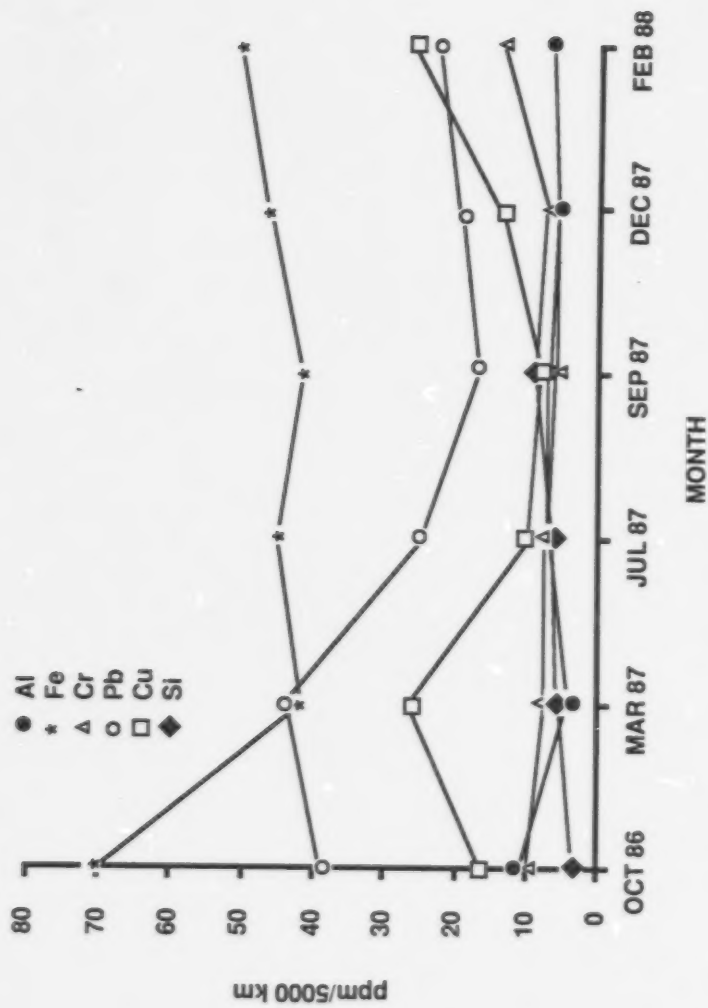


Figure 12/ Used-Oil Analysis, Car 342

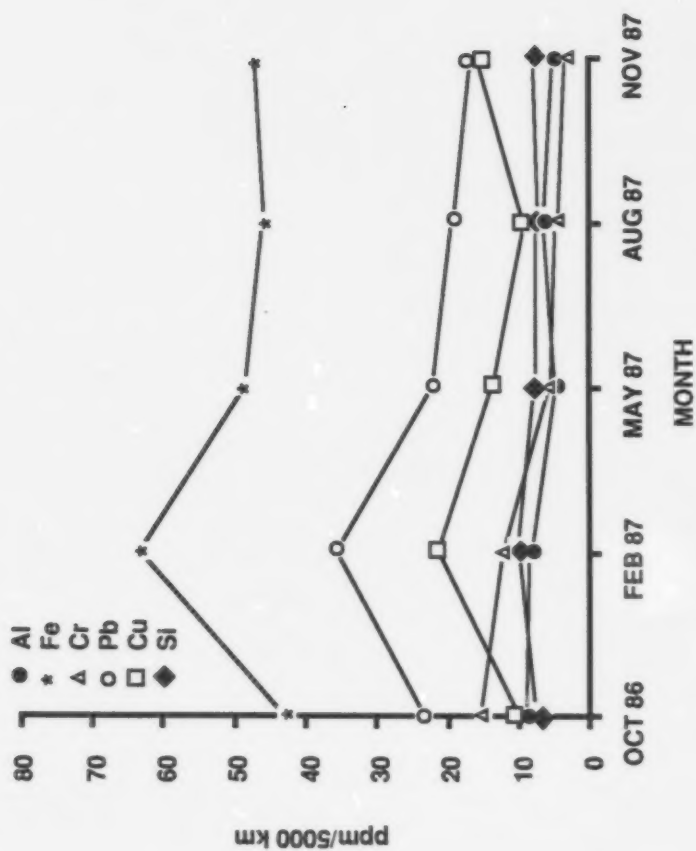


Figure 13/ Used-Oil Analysis, Car 344

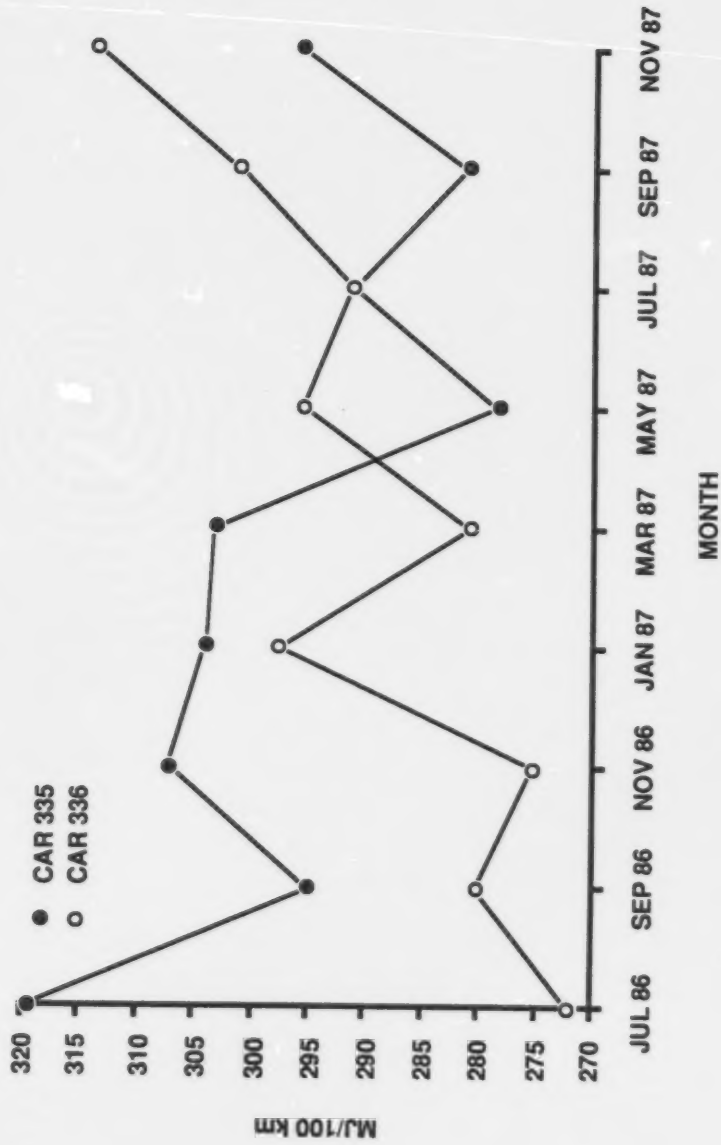


Figure 14/ Fuel Consumption, Gasoline Car

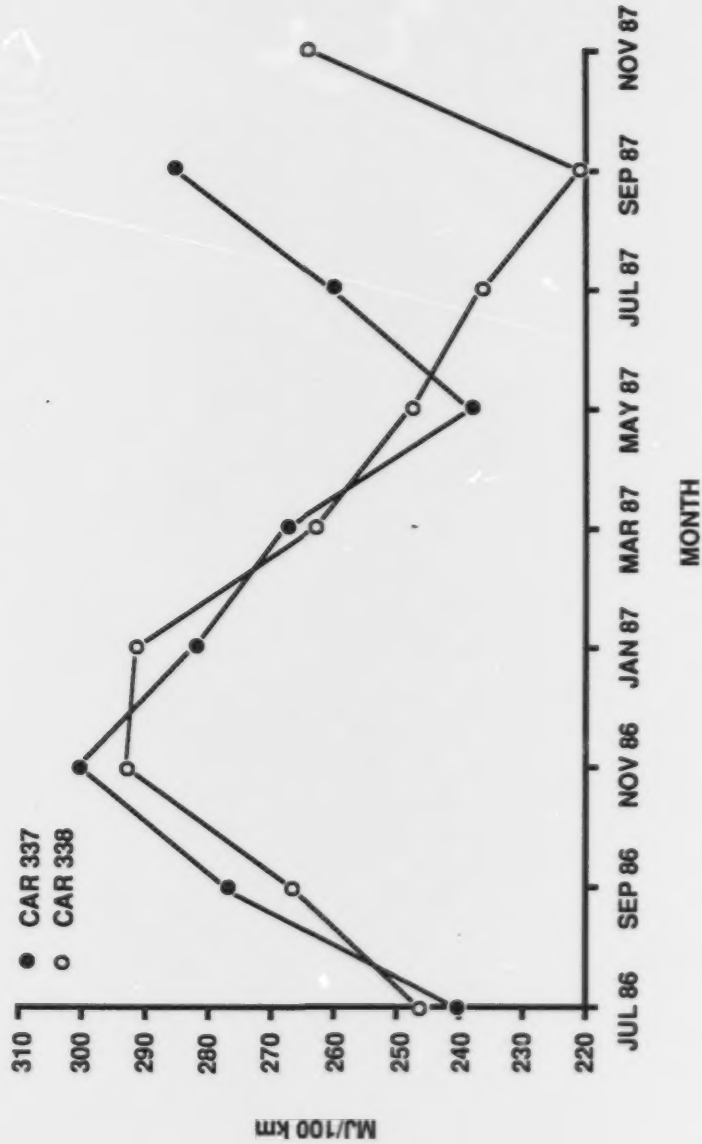


Figure 15/ Fuel Consumption, M85 Cars

APPENDIX A/ TEST VEHICLE IDENTIFICATION

Appendix A/ Test Vehicle Identification

Test Car No.	Location and Fuel	License Plate No.	Colour	Body Style	Vin
335	Gasoline	VAB 235	Tan	4 door Htchbk.	1FABP1479DW243333
336	Gasoline	VAB 236	Yellow	4 door. Htchbk.	1FABP1475DW243331
337	M85	VAB 237	White	4 door Htchbk.	1FABP1473DW243327
338	M85	VAB 238	Black	4 door Htchbk.	1FABP1471DW243326
342	Ford-M85	TML 613	Tan	4 door Wagon	1FABP1075DW243334
343	Ford-M85	TMM 611	Maroon	4 door Wagon	1FABP1075DW243335
344	Ford-M85	TMK611	Rd	4 door Htchbk.	1FABP1070DW242220

APPENDIX B/ USED-OIL ANALYSIS RESULT INTERPRETATION

Appendix B/ Used-Oil Analysis Result Interpretation

Test	Results "Warning Limits"	"Median"	"90%ile"	"Typical"	"Range"	Components
TBN	50% drop	—	—	—		
Visc. @ 100°C	25% drop	—	—	—		
Pentane Insol., % by mass	>1.5	—	—	—		
Al ppm	>40	19	15	—	15-40	pistons
Cr ppm	>40	6.4	—	—	5-30	rings
Cu ppm	>40	22	35	—	5-40	bearings, bushings
Fe ppm	>100	47	75	—	40-200	cylinders
Pb ppm	>40	—	—	—	—	bearings
Si ppm	>20	18	17	20	5-25	dirt
Source	1	2	3	4	5	

— All above data refer to used oil condition at drain.

- Sources
- 1/ "Testing Used Engine Oils," Chevron Research Co., 1983
 - 2/ SAE Paper 77-642 (on diesel engines)
 - 3/ SAE Paper 73-745 (on diesel engines)
 - 4/ Fuels and Lubes Magazine, September/October 1980
 - 5/ SAE Paper 77-85 (on automobile engines)

APPENDIX C/ A SURVEY OF GASOLINE ENGINE FIELD TESTS

Appendix C/ A Survey of Gasoline Engine Field Tests

Reference	Pless, L.G., "A Study of Lengthened Engine Oil-Change Intervals", SAE Paper 740139.
No. of Vehicles	109
Oil Type	9 oils, SC, SD, SE quality
Oil Viscosity Grade	20, 30, 40
Oil Drain Period	16 100 to 41 800 km
Distance Travelled	37 000 to 257 500 km
Parameters Measured	Cam & Lifter, Ring Gap
Results	
To Final Distance Accumulation (per 257 500 km)	50 000 km Equivalent

Cam & Lifter Wear:

17 cars; 95 to 155 $\mu\text{m}/$ (S. Florida Taxis, 1971)	18.4 to 30.1 μm
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18 cars; 65 to 195 $\mu\text{m}/$ (S. Florida Taxis, 1972)	12.6 to 37.9 μm
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11 cars; 70 to 90 $\mu\text{m}/$ (C. Indiana Taxis, 1971)	13.6 to 17.5 μm
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Ring Gap Growth:

17 cars; Top: 350 to 650 $\mu\text{m}/$ 2nd: 325 to 575 $\mu\text{m}/$ (S. Florida Taxis)	68.0 to 126.2 μm 6.31 to 111.7 μm
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18 cars; Top: 250 to 525 $\mu\text{m}/$ 2nd: 325 to 450 $\mu\text{m}/$ (S. Florida Taxis)	48.5 to 101.9 μm 63.1 to 87.4 μm
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11 cars; Top: 175 to 200 $\mu\text{m}/$ 2nd: 325 to 400 $\mu\text{m}/$ (C. Indiana Taxis)	34.0 to 38.8 μm 63.1 to 77.7 μm
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Reference	Rodgers, J.J. and Kabel, R.H., "Vehicle Evaluation of Synthetic and Conventional Oils," SAE Paper 750827.	
No. of Vehicles	5	
Oil Type	3 Synthetic, 1 Conventional	
Oil Viscosity Grade	5W20, 10W40	
Oil Drain Period	12 000 to 32 000 km	
Distance Travelled	64 000 km	
Parameters Measured	Cam Wear, Sludge, Varnish, and Rush	
Results		
To Final Distance Accumulation (@ 64 000 km)		50 000 km Equivalent

Cam Wear:	0.002 mm to 0.012 mm average	1.56 to 9.38 μm
Sludge	9.6 to 9.8 average (10 = Clean)	9.7 to 9.8
Varnish	9.7 to 9.8 average (10 = Clean)	9.8
Rust	8.5 to 9.1 average (10 = Clean)	8.8 to 9.3
Comments:	Mild test, Minimal wear No advantage of synthetics over conventional oils apparent	

Reference Pless, L.G. and Rodgers, J.J., "Cam and Lifter Wear as Affected by Engine Oil ZDP Concentration and Type," SAE Paper 77087.

No. of Vehicles 127

Oil Type SE/CC, SE/CD

Oil Viscosity Grade 10W40, 30 20W20

Oil Drain Period 4800 to 41 800 km

Total Distance
Travelled 37 000 to 259 100 km

Parameters Measured Cam and Lifter Wear

Results

To Final Distance Accumulation 50 000 km Equivalent
(per 10 000 km)

Cam & Lifter Wear

15 cars; 4.6 to 10.7 $\mu\text{m}/$
(Indianapolis Taxis)

23 to 53.5 μm

19 cars; 1.3 to 4.6 $\mu\text{m}/$
(Lansing Police Cars)

6.5 to 2.3 μm

17 cars; 11.9 to 20.1 $\mu\text{m}/$
(Phoenix and Los Angeles Taxis)

59.5 to 100.5 μm

5 cars; 10.1 $\mu\text{m}/$
(San Diego Taxis)

50.5 μm

2 cars; 3.3 $\mu\text{m}/$
(California State Cars)

16.5 μm

6 cars; 2.2 to 4.4 $\mu\text{m}/$
(GMR General Transportation Cars)

11 to 22 μm

8 cars; 4.7 to 13.1 $\mu\text{m}/$
(Ft. Lauderdale Taxis)

23.5 to 65.5 μm

Reference Bardy, D.C., et al, "A 2.3L Engine Deposit and Wear Test – An ASTM Task Force Progress Report," SAE Paper 780260.

No. of Vehicles	61
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Oil Type	Various
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Oil Viscosity Grade	Various
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Oil Drain Period	9 700 to 32 200 km
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Total Distance	
Travelled	37 200 to 259 100 km

Parameters Measured Sludge, Varnish, Cam Wear, Cylinder Bore Wear, and Bearing Weight Loss (not done on all cars)

Results

To Final Distance Accumulation 50 000 km Equivalent

Sludge	5.8 to 9.5 (10 = Clean)	9.3+
Varnish	3.6 to 7.8 (10 = Clean)	7.3 to 9.0
Cam Wear	30.5 to 53.3 μm	<25.5
Lifter Wear	35.6 to 63.5 μm	25.5
Cylinder Bore Wear	5.1 to 86.4 μm	<38.0
Bearing Weight Loss	73 to 184 mg	<77.3

Reference	Miller, M.S. et al, "A Field Correlation of the Sequence V-D Engine Test," SAE Paper 820084.
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No. of Vehicles 5

Oil Type SF, SE/CD

Oil Viscosity Grade 5W30, 15W40

Oil Drain Period	12 000 and 24 000 km
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**Total Distance
Travelled** 72 000 km

Parameters Measured Sludge, Varnish, Cam Wear, and Rod Bearing Weight Loss

Results

To Final Distance Accumulation 50 000 km Equivalent

Sludge	9.6 to 9.7 @ 72 000 km (10 = Clean)	9.8
Varnish	8.5 to 9.4 @ 72 000 km (10 = Clean)	9.0 to 9.6
Cam Wear	5 µm to 10 µm in for SF oils @ 72 000 km	3.5 to 6.9
	46 m for SE/CD oil @ 53 700 km	43

Rod Bearing Weight Loss	32.4 to 42.9 mg for SF oils @ 72 000 km 64.7 mg for SE/CD oil @ 53 700 km	22.5 to 29.8 60.2
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Reference	Flathmann, D.E. et al, "Wear Performance of an SAE 0W30 Partial-Synthetic Motor Oil Under High Speed Driving Conditions," SAE Paper 821196.
No. of Vehicles	6
Oil type	SF Quality
Oil Viscosity Grade	0W30, 10W30
Oil Drain Period	12 000 km
Total Distance Travelled	80 000 km
Parameters Measured	Rod Bearings, Main Bearings, Piston Rings, Cylinder Bore, Cam Wear, Sludge, Varnish, and Used-Oil Analysis

Results

To Final Distance Accumulation (per 80 000 km)	50 000 km Equivalent
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Rod Bearing Weight Loss	42.6 mg	26.6
Main Bearing Weight Loss	48.9 mg	30.6
Piston Ring Weight Loss	Top 41.9 mg	26.2
	2nd 25.2 mg	15.8
Cylinder Bore Wear	4.3 μm	2.7
Cam Wear	12 μm	7.5
Sludge	9.8 (10 = Clean)	9.9
Varnish	8.7 (10 = Clean)	9.2
Used-Oil Analysis	(@ 12 000 km drain intervals)	(per 5000 km)
	Al 18, 3, 9 (10 ave.) ppm	4.2 ppm
	Cr 2, 1, 1 (1 ave.) ppm	<1.0 ppm
	Cu 3, 33, 3 (13 ave.) ppm	5.4 ppm
	Fe 37, 15, 50 (34 ave.) ppm	5.0 ppm
	Si 23, 7, 7 (12 ave.) ppm	
	Pb 39, 45, 42 (42 ave.) ppm	17.5 ppm

Reference Harris, S.W. and Zahalka, T.L., "A Field Test Study of Camshaft Wear in a 2.3 L OHC Engine and its Correlation to the Sequence V-D Test," SAE Paper 831758.

No. of Vehicles 20

Oil type 5 types SF/CC, SF/CD Quality

Oil Viscosity Grade 15W40 and 10W30

Oil Drain Period 24 000 km

Total Distance Travelled 48 000 to 80 000 km

Parameters Measured Camshaft Wear

Results

To Final Distance Accumulation 50 000 km Equivalent

Cam Wear	12.7 to 20.3 μm @ 16 000 km	39.7 to 63.4
	15.2 to 25.4 μm @ 24 000 km	31.7 to 52.9
	17.8 to 38.1 μm @ 48 000 km	18.5 to 39.7
Follower Wear	<9 mg weight loss @ 16 000 km	<28.1
	<17 mg weight loss @ 24 000 km	<35.4
Iron Level	163 to 227 ppm @ 24 000 km (1st drain)	34 to 47 ppm (per 5000 km)
	145 to 267 ppm @ 48 000 km (2nd drain)	30 to 56 ppm (per 5000 km)
Comments	- Cam wear is an inverse exponential relation - Long drain periods accentuate wear problems	

Reference Smolenski, D.J. and Kabel, R.H., "Effect of Engine Oil Zinc Dithiophosphate (ZDP) Additive Type on Cam and Lifter Wear in Taxi Service" SAE Paper 831760.

No. of Vehicles 56

Oil Type 9 types, 3SF, 6 < SF Quality

Oil Viscosity Grade 10W30, 20W30

Oil Drain Period 12 000 km $\pm$ 1 200 km

Total Distance
Travelled 108 000 to 165 000 km

Parameters Measured Sludge, Varnish, Cam and Lifter Wear

Results

To Final Distance Accumulation 50 000 km Equivalent
(per 161 000 km)

Sludge	9.3 to 9.6, (10 = Clean)	9.8, 9.9
Varnish	6.0 to 7.3, (10 = Clean)	8.8 to 9.2
Cam and Lifter Wear		
Average	86 to 246 μ m	26.7 to 76.4 μ m
Maximum	445 to 1412 μ m	138.2 to 438.5 μ m
Comments	Long drains in severe service Average Cam and Lifter Wear $\leq 150 \mu$ m Acceptable	46.6 μ m

Reference Olson, D.M. and Pullen, G.A., "Engine Wear Protection of SAE 5W-30 Oils," SAE Paper 852075.

No. of Vehicles 4

Oil Type 2; SF 5W30

Oil Viscosity Grade 5W30

Oil Drain Period 12 000 km

**Total Distance
Travelled** 82 000 km

Parameters Measured Sludge, Varnish, Bearing Wear, and Used-Oil Analysis

Results

To Final Distance Accumulation 50 000 km Equivalent

Sludge	9.6 to 9.9, (10 = Clean)	9.8 to 9.9
Varnish	8.2 to 8.6, (10 = Clean)	8.9 to 9.1
Piston Varnish	7.9 to 8.9 (10 = Clean)	8.1 to 8.7
Main Bearings	11.6 to 192.4 mg average	7.1 to 117.3
Rod Bearings	39.8 to 169.4 mg average	24.3 to 103.3

Wear Metals

	(12 000 km intervals)	(per 5000 km)
Fe	36.4, 34.0, 31.6, 32.6, (33.7 ave.) ppm	14 ppm
Cu	5.3, 6.0, 8.6, 6.4, (6.6 ave.) ppm	3 ppm
Pb	25.9, 28.0, 75.0, 70.0, (49.9 ave.) ppm	21 ppm